The MINERνA Experiment

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On Behalf of the

MINERνA Collaboration

Introduction

1. What physics topics are accessible to Minerνa?

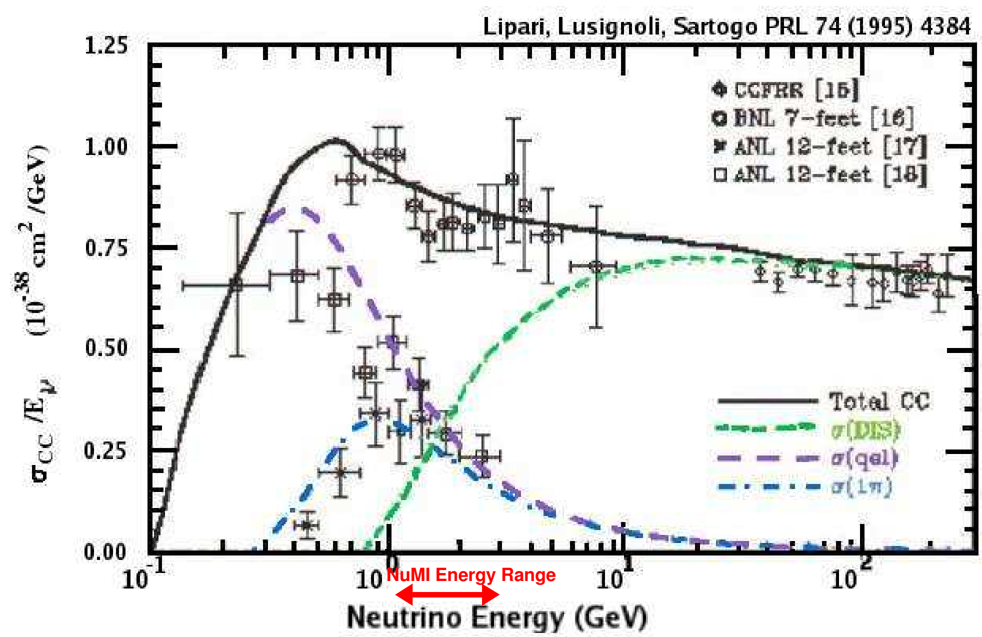
2. Why are these topics important?

3. How will Minerνa address this physics?

Physics Topics Accessible to Minerνa

Physics Topic	*Experimental Need*
Deeply-Inelastic Scattering:	Improved statistics with better determination of final states
Quasi-Elastic Scattering: Axial Form Factor of Nucleon	Improved Precision over a wide Q^2 Range
Coherent Scattering: Single Pion Production	1) Improved statistical precision of total cross section 2) Measurements of nuclear dependence (A-dependence)
Resonance Production: Both Neutral Current (NC) and Charged Current (CC)	1) Improved statistical precision with 1-5 GeV neutrinos 2) Quark-Hadron Duality
Nuclear Physics	Precision studies of neutrino-nucleus scattering as compared to charged lepton-nucleus scattering.

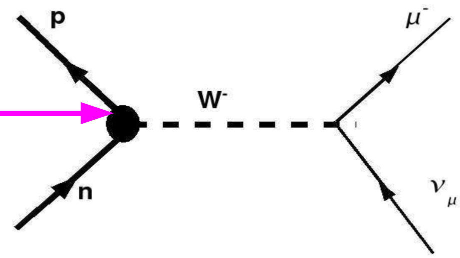
Existing Measurements of Neutrino-Nucleon Cross Section



Quasi-Elastic Neutrino Scattering

$$\nu_\mu(\overline{\nu}_\mu)n(p)\rightarrow\mu^+(\mu^-)p(n)$$

$$\langle p|J_\lambda^+|n\rangle=\overline{u}[\gamma_\lambda F_V^1(q^2)+i\sigma_{\lambda\nu}q^\nu\frac{\xi F_V^2(q^2)}{2M}+\gamma_\lambda\gamma_5F_A(q^2)+q_\lambda\gamma_5\frac{F_P(q^2)}{M}]u$$

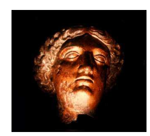


$F_v^1(q^2)$ & $F_v^2(q^2)$ are the Vector Form Factors

(extractable from G_E^N, G_M^N)

$F_A(q^2)$ is the Axial Form Factor

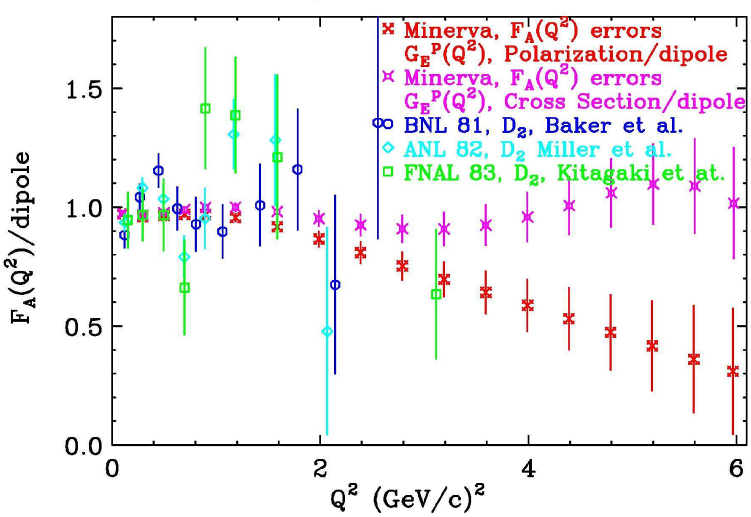
(extractable from neutrino scattering!)



Form Factor Measurements

MINERνA Measurement of Axial FF

QE scattering, ν_μ, $F_A(Q^2)$/dipole, M_A=1.014 GeV



Minerva estimated $F_A(Q^2)$ statistical precision based on Monte Carlo simulation attached to the electric form factor, $G_E^p(Q^2)$, for the nucleon to indicate scale.

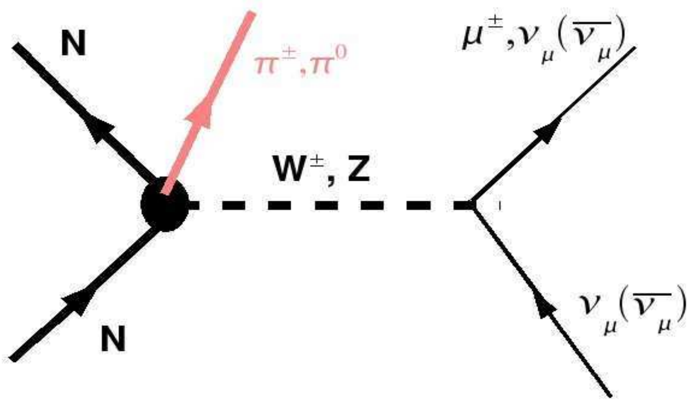
The $G_E^p(Q^2)$ scales used in this plot are based on polarization transfer measurements performed at Jefferson Lab (red) and measurements of the total elastic electron-nucleon scattering cross section (magenta).

The Axial Form Factor of the Nucleon is poorly known...

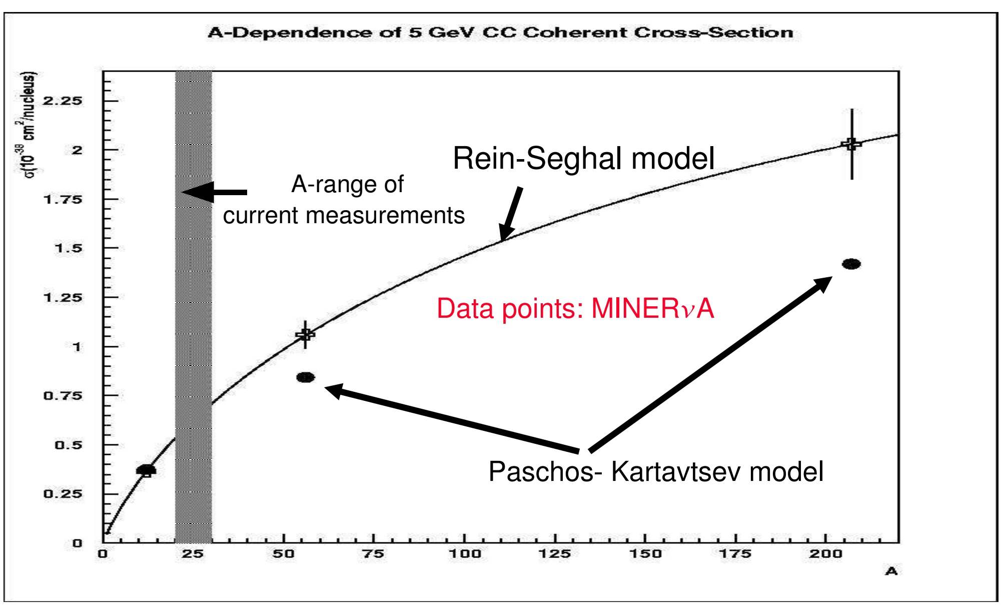
Coherent Neutrino Scattering

$\nu_\mu(\overline{\nu}_\mu)\,N \rightarrow \mu^+(\mu^-)\,\pi\,N$ *Charged Current*

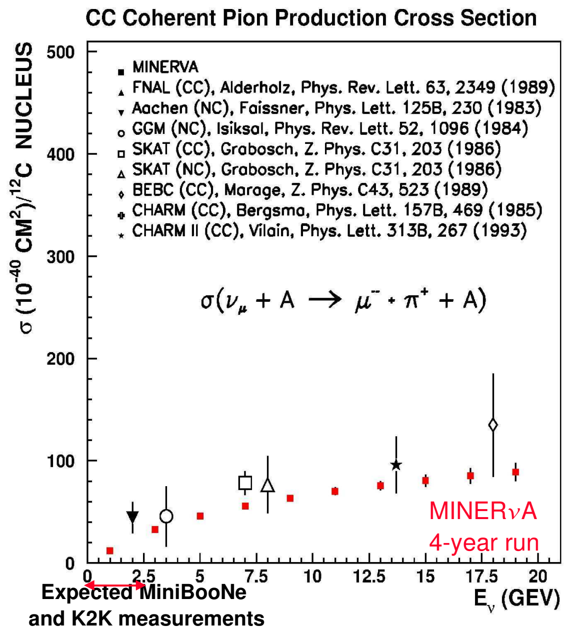
$\nu_\mu(\overline{\nu}_\mu)\,N \rightarrow \nu_\mu(\overline{\nu}_\mu)\,\pi\,N$ *Neutral Current*



Coherent Pion Production: A Window on the Weak Interaction



Example of MINERνA's Analysis Potential Coherent Pion Production



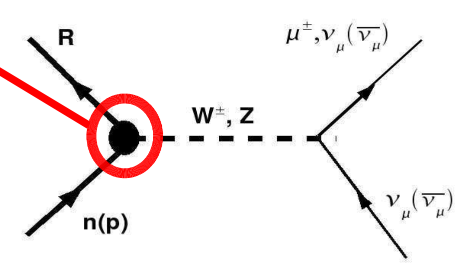
Resonance Production

$$\nu_\mu(\overline{\nu}_\mu)\, n\,(p) \rightarrow \mu^+(\mu^-)\, R \textit{ Charged Current}$$

$$\nu_\mu(\overline{\nu}_\mu)\, n\,(p) \rightarrow \nu_\mu(\overline{\nu}_\mu)\, R \textit{ Neutral Current}$$

Form Factors are needed to describe the N-Resonance transitions.

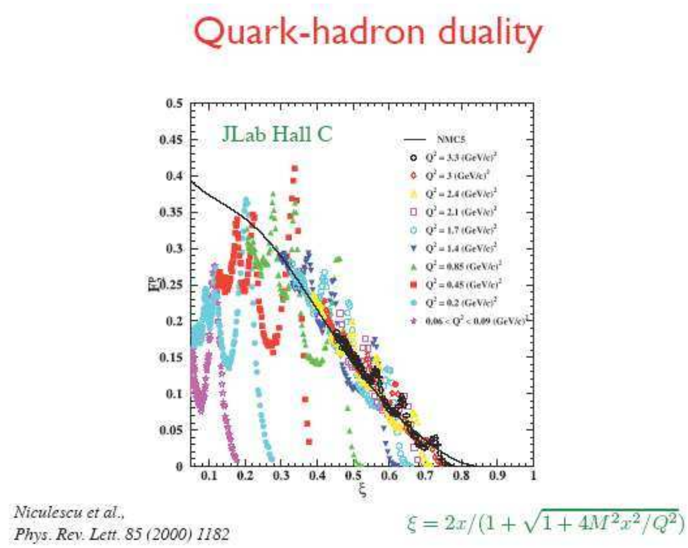
- electron scattering probes vector component of these form factors
- neutrino scattering will probe axial component



Cross sections, thus the form factors, for neutrino excitation of resonances are virtually unknown.

Quark-Hadron Duality

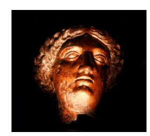
Quark-Hadron Duality: The relationship between the DIS structure function F_2 and the average resonance cross section as measured in electron scattering.



The cause of quark-hadron duality is not well known...

Neutrino scattering will help untangle this phenomena since neutrino interactions explicitly provide insight into flavor dependent behavior.

Nuclear Effects



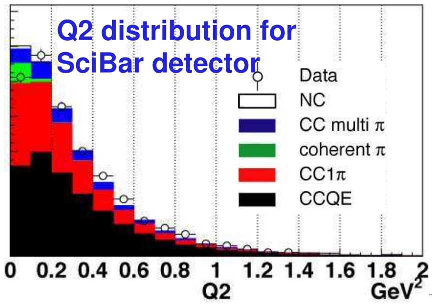
The Past: Neutrino interactions were measured on heavy nuclei with low statistical precision; nuclear effects could be ignored...but...

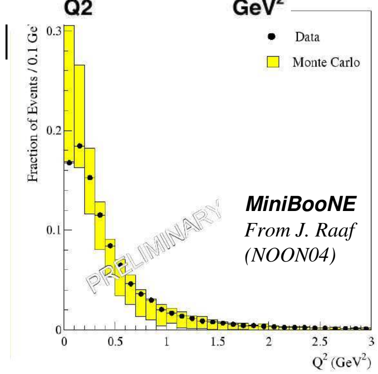
The present: interactions are being measured with increasing precision; nuclear effects are now important...so...

The future: precision A-dependence studies must be performed!

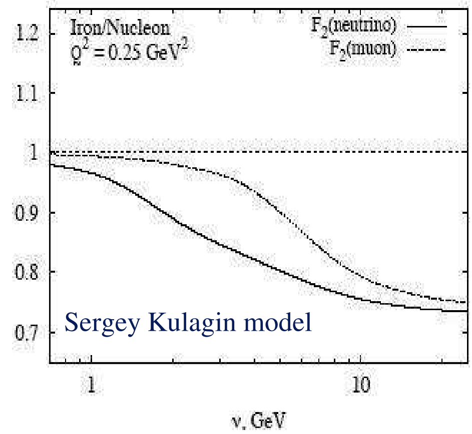
Nuclear Effects

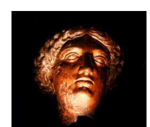
Predicted difference ν-A vs e/μ-A





MINERνA should be able to determine this ratio to a few percent for n > 6 GeV.





Why are these Topics Important?

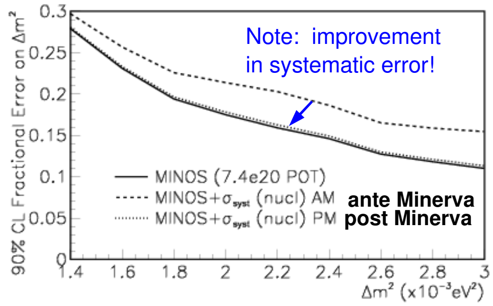
Physics Topic	Experimental Need
Deeply-Inelastic Scattering:	Observed energy in detectors can be obscured by final state interactions in nuclear media.
Quasi-Elastic Scattering: Axial Form Factor of Nucleon	1) The axial form factor of the nucleon is poorly known. 2) Cross section uncertainties are a major portion of oscillation experiment error budgets.
Coherent Scattering: Single Pion Production	1) Coherent scattering is, in general, a good probe of the weak interaction. 2) Coherent scattering is expected to be a large background for future precision neutrino oscillation experiments.
Resonance Production: Both Neutral Current (NC) and Charged Current (CC)	Improved understanding of the transition from quasi-elastic processes to deeply-inelastic scattering processes in the weak sector.
Nuclear Physics	1) Nuclear medium dependence of neutrino interactions is important for interpretation of future neutrino oscillation studies. 2) Differences are expected between charged and neutral lepton structure functions.

For Example: Helping MINOS and NOνA/T2K

Measurement of Δm^2 with MINOS:

Needed: detailed understanding of the relationship between the incoming neutrino energy and the visible energy in the detector

From: precision cross section measurements and neutrino-initiated nuclear reactions

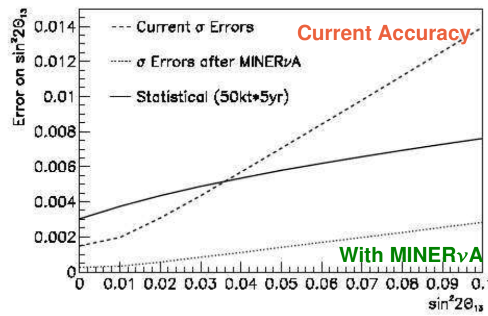


Measurement of $\sin^2 \Theta_{13}$ with NOνA:

Needed: absolute cross sections of signal & background reactions

From: precision cross section measurements

see: D. A. Harris, et al., hep-ex/041005 for further info...



How will Minerνa Achieve these Physics Goals?

- ✗ Lots of Neutrinos
  - ✓ Provided by the NuMI Beam at FNAL
    - ✓ approximately 10^3 times more intense than previously available beams!
- ✗ Massive Detector with:
  - ✓ Good Tracking Resolution
  - ✓ Good Momentum Resolution
  - ✓ Low Momentum Particle Detection Threshold
  - ✓ Particle Identification Capabilities
- ✗ Array of Nuclear Targets
  - ✓ Carbon
  - ✓ Iron
  - ✓ Lead

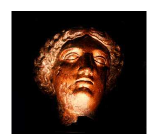
What is Minerνa?

Main INjector ExpeRiment ν-A*

MINERνA is a compact, fully active neutrino detector designed to study neutrino-nucleus interactions with unprecedented detail.

*Minerva, pictured above, was the Roman goddess of wisdom and technical skill.

The MINERνA Collaboration



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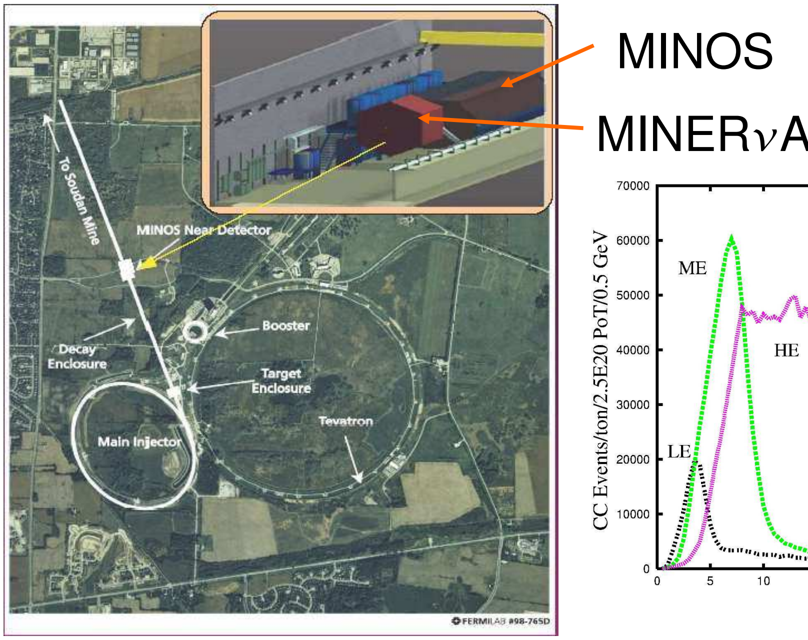
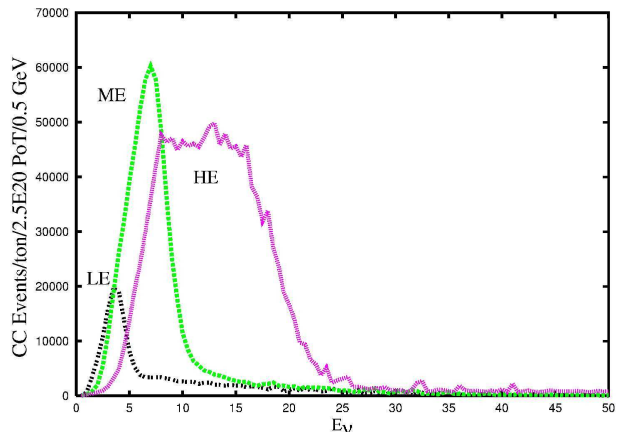
Collaboration of:

Particle, Nuclear, and Theoretical physicists

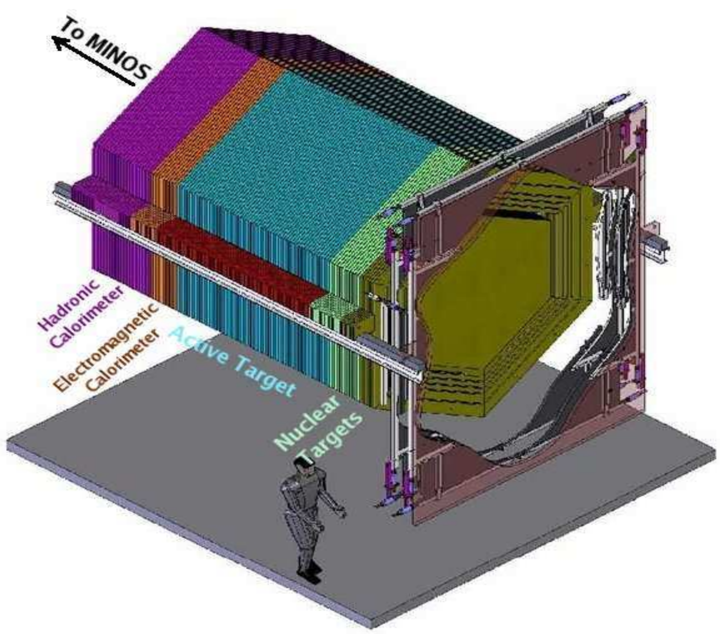
* Co-Spokespersons
# Members of the MINERvA Executive Committee

Lots of Neutrinos-NuMI Beam Line



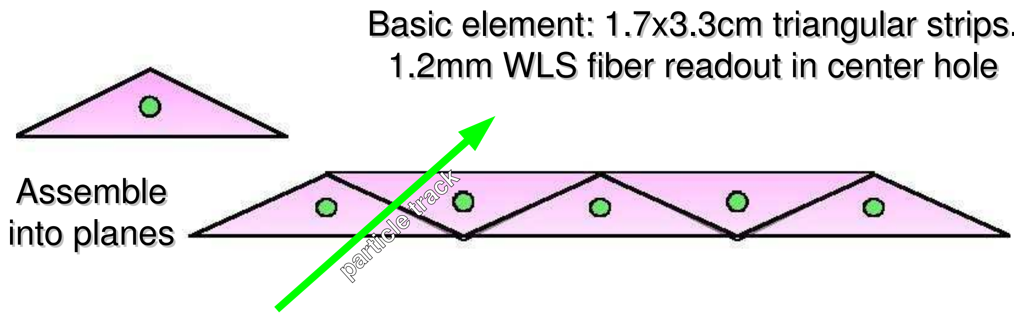


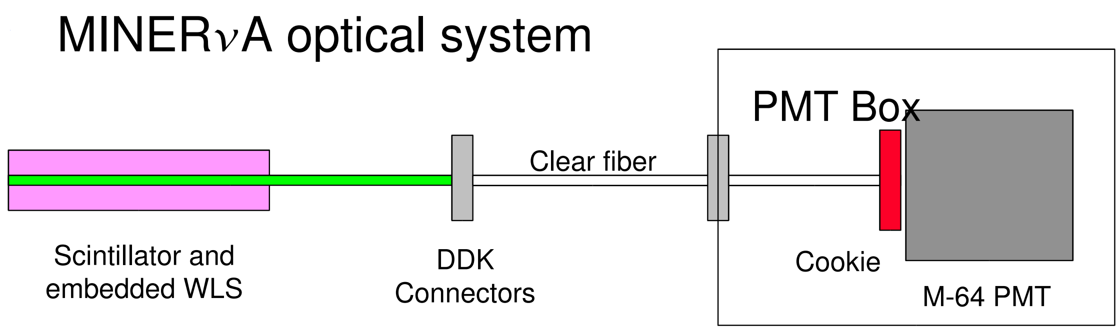
The MINERνA Detector



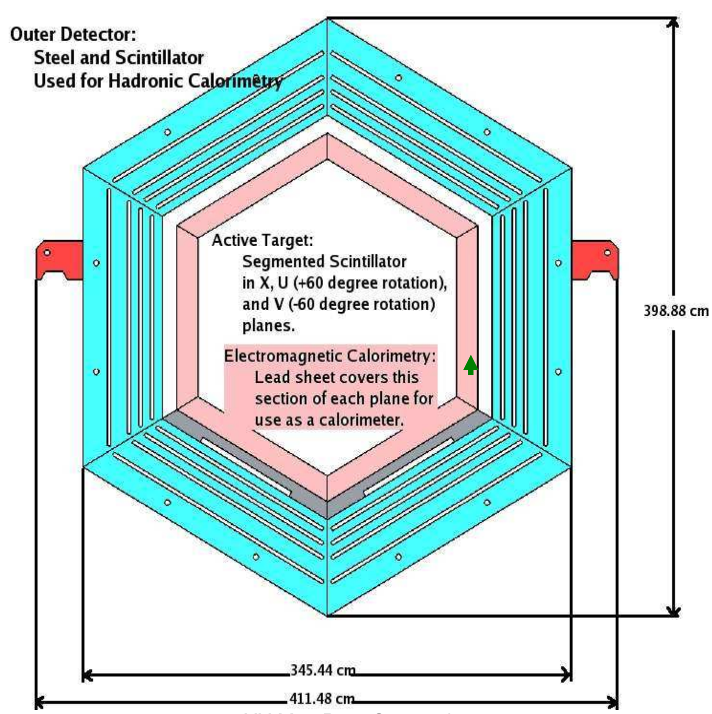
- Nuclear Targets:
  - 1/2 Ton each carbon, iron, and lead
- Active Target:
  - 5.78 Tons segmented scintillator planes
- Electromagnetic Calorimeter:
  - Interleaved lead sheet (0.2 cm thick) with segmented scintillator planes
- Hadronic Calorimeter:
  - Interleaved Iron sheet (2.54 cm thick) with segmented scintillator planes

Active Detector Elements





Front View of Detector



Event Rates:

13 Million Total CC events

4 - year run

Fiducial Volume:
3 tons Polystyrene, ≈ 0.6 t C, ≈ 1/2 t Fe and ≈ 1/2 t Pb
Expected CC event samples:
8.6 M ν events in Polystyrene
1.4 M ν events in C
1.4 M ν events in Fe
1.4 M ν events in Pb

Charged-Current Physics Topic	***Expected Statistics***
	3 Tons of Polystyrene
Quasi-Elastic	**0.8 M**
Resonance	**1.6 M**
Transition: Resonance to DIS	**2 M**
DIS and Structure Functions	**4.1 M**
Coherent Pion Production	**85 K CC/37 K NC**

Current Status of MINERνA

- MINERνA is an established project and approved by FermiLab.
- Component research and development, and prototyping, are well underway at our member institutions.
- Current scheduling model indicates construction starting in Oct. 2006 and installation-finishing/commissioning-starting in early Fall 2008.

Summary

1. What physics topics are accessible to Minerνa?
   A. Minerνa will provide improved precision neutrino-nucleus cross section measurements at neutrino energies from 1 to 15 GeV.
   B. Minerνa will be able to investigate DIS, quasi-elastic, coherent, and resonance processes with precision much improved over most present neutrino cross section measurements.
2. Why are these topics important?
   A. Coherent processes comprise a significant source of background for neutrino future neutrino oscillation studies.
   B. Cross sections for resonance production in neutrino scattering are relatively unknown.
   C. Nuclear medium effects from neutrino interactions are expected to differ from their charged-lepton counterparts.
   D. Neutrino-nuclear effects have not been studied in high-mass targets.
   E. The axial form factor of the nucleon is poorly known.
3. How will Minerνa address this physics?
   A. Minerνa is a multi-ton detector designed specifically for precision cross section measurements.
   B. Minerνa will make use of the high-intensity neutrino beam from NuMI.
   C. Minerνa is outfitted with an array of nuclear targets for the express purpose of high-precision studies of nuclear medium effects in neutrino interactions.